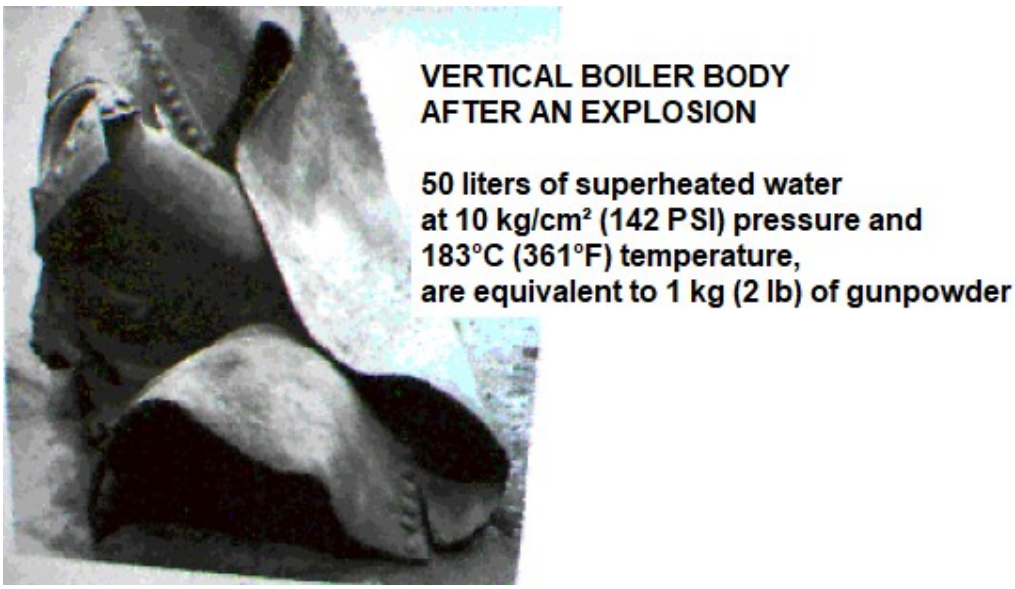
CHAPTER 2: Steam and Water part 1

Part 1 - Steam:

Water, in the form of steam, is the element responsible for transporting the heat generated during combustion (rapid oxidation of the fuel) to the point or location where this heat will be used for a thermal or mechanical process. There, it will revert to water (condensate), which may or may not be recovered.

This means that water only acts as a "heat or energy conveyor belt."

However, while it is an easily obtainable medium with many advantages, it also has its problems. Therefore, we must understand its mechanics and the issues involved in its use. In its application, we will use pressure and temperature as constant parameters to define its condition, and we will also refer to the unit of heat.


VERTICAL BOILER BODY
AFTER AN EXPLOSION
50 liters of superheated water
at 10 kg/cm² (142 PSI) pressure and
183°C (361°F) temperature,
are equivalent to 1 kg (2 lb) of gunpowder

Let's clarify these terms: Pressure: We can define it as the expression that indicates the units of force applied per unit area.

Depending on the units used to measure force and the units of area, we can talk about kilograms per square centimeter (kg/cm²), pounds per square inch (PSI): lb/in² or lb/in², etc.

It can also refer to a comparison with other pressures: such as atmospheric pressure, the pressure exerted by a certain height (expressed in m, cm, mm, or inches) of water or another liquid (for example, mercury), etc.

All these units can be expressed in an equivalent form if we use a conversion factor.

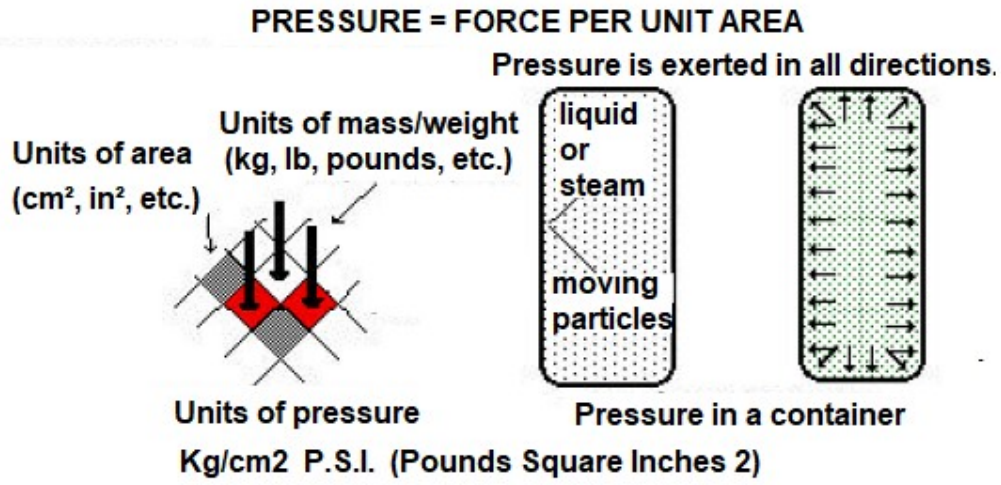
For example:

1 kg/cm² multiplied by 14.22 gives us the pressure in PSI (lb/in²).

1 kg/cm² multiplying this by 10 gives us the pressure in meters of water column.

The pressure indicated by pressure gauges is generally the "gauge" pressure.

The "absolute" pressure is the sum of the atmospheric pressure and the gauge pressure.



But what is pressure in liquids and gases (vapors)?

It is the force exerted by molecules on the walls that confine (contain or support) them. A molecule is the smallest part of a pure chemical substance that can be identified as such—if we break a molecule, it will cease to be that substance and transform into another.

If we disregard the weight of liquids and gases (vapors) and consider the weight of the molecules as projectiles, we see that these particles exert pressure in the form of "impacts" on the walls (of the containers).

We can increase these "impacts" by "reducing the size of the container" (or increasing the amount of substance inside) or by increasing the speed of the molecules (number of impacts) by increasing their temperature (their energy level).

In other words, we can increase pressure by "pumping" (with a pump) the fluid or by increasing the energy of the fluid (by supplying it with heat, as in boilers).

Since these "impacts" occur continuously and "hit" the walls of the container, this causes the pressure to be exerted equally in all directions (this is not so much the case when we consider the pressure exerted by simple weight - the "lower" a wall of the container is located, the greater the pressure it must withstand due to the "pure" weight of the substance: the force of gravity).

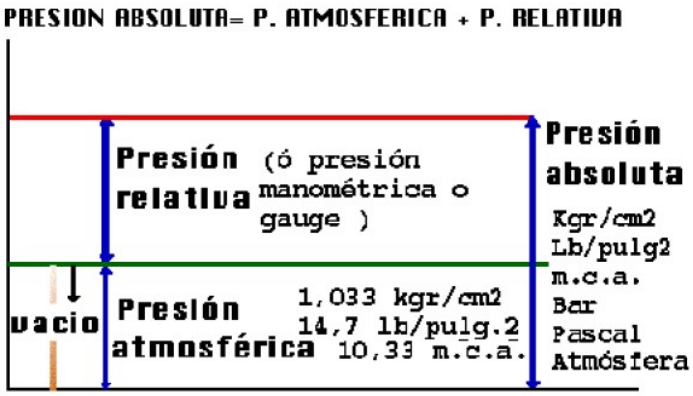
EXPLOSION OF A SMALL HEATING BOILER

We will see that a "pressurized" container does not necessarily "explode" with compressed gases inside. Rather, these gases can form and expand from "superheated" liquids (such as hot water with temperatures above 100°C or other gases at lower temperatures, such as those used in refrigeration (ammonia, freon, etc.) or even for extinguishing fires, like CO2).

These "superheated" liquids, upon contact with lower pressures, vaporize and "expand," creating a volume many times greater than the one they occupy, as is the case in the previous photograph. In a relatively "small" heating boiler, for some reason the water temperature rose well above 100°C, causing high pressure in the container that made it "explode." The expansion of the vapor against the walls (with their large surface area) exerted its pressure and, consequently, a great force (due to the large surface area), resulting in what the image shows. (the explosion of a bomb).

In boilers, we will use pressure gauges to measure the pressure. We must carefully check the pressure units marked or engraved on the gauge (the units in which the pressure is indicated) and whether these correspond to absolute or relative readings.

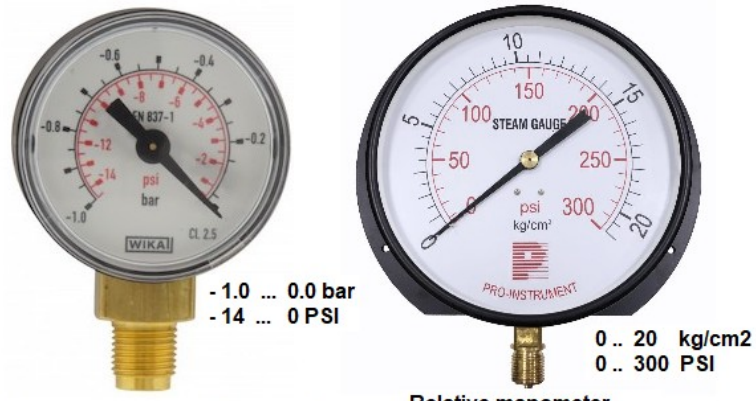
Absolute pressure is the pressure indicated by a pressure gauge that displays atmospheric pressure (approximately 1 when its units are expressed in atmospheres, 1.033 kg/cm², or 14.7 PSI when it displays pounds per square inch) when its connection is exposed to the atmosphere (meaning that to read zero pressure, a complete vacuum must be created at its connection or port).



Gauge pressure, also known as relative pressure, is the pressure indicated by a pressure gauge that reads zero when its connection is exposed to the atmosphere.

Absolute pressure is equal to the sum of gauge pressure and atmospheric pressure (expressed in the same units: 1.033 kg/cm², 1 atmosphere, or 14.7 PSI, etc.).

We must be very careful when we say "pressure" to clarify which of the two we are referring to. (Generally, the pressure on pressure gauges is relative, which is why relative pressure is called "gauge" or "manometric pressure" in English).



Absolute or Vacuum Pressure Gauge scale in PSI bar (1 bar = 1.02 Kg/cm2)

Relative manometer scale in PSI and Kg/cm2

Boiler pressure gauges are suitable for this use (accuracy and temperature), and it is important to check them periodically (it may vary due to wear or fatigue), since the working effort that the boiler endures will be indicated by this pressure.

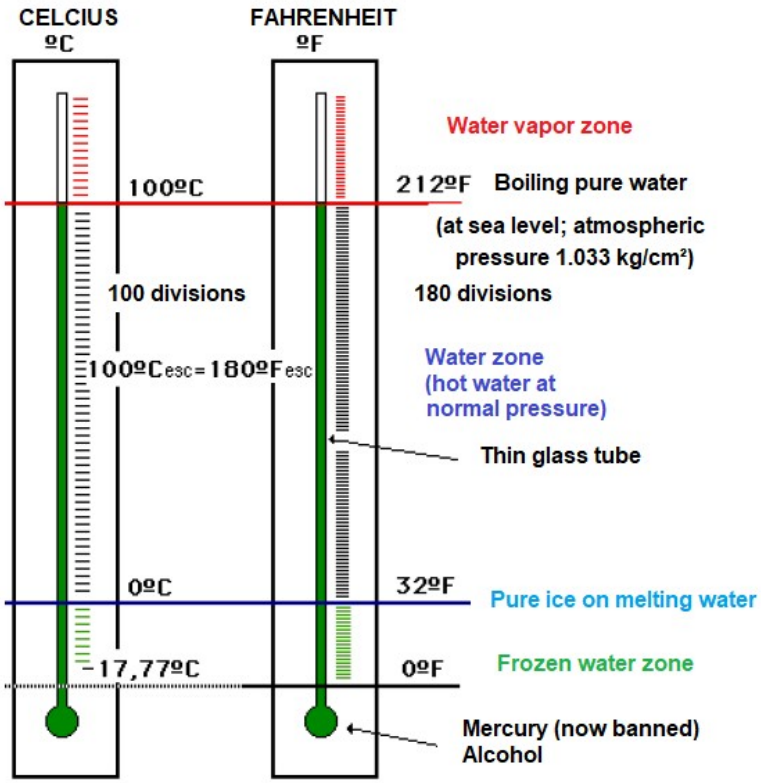
The pressure of water and steam in a boiler, when dealing with saturated steam and boiling water, accumulates thermal energy. If

this energy is released as mechanical energy (expansion) when the vessel containing and confining it (the boiler) ruptures (due to excessive pressure, poor construction, thermal or mechanical aging, corrosion, overheating, etc.), the vessel breaks and the resulting shock wave exerts pressure on the surrounding walls or any objects in its path, with catastrophic consequnces. See the previous figure of a vertical boiler, which, after rupturing or exploding, was projected hundreds of meters from its installation location.

TEMPERATURE

Temperature can be defined as the indication of the degree (energy level) of heat in bodies. Its numerical value depends on the temperature scale to which it is referenced and the starting point of the measurement (its zero point). We will generally work with two systems of units: degrees Celsius (°C) or degrees Fahrenheit (°F).

Temperature is measured with thermometers (temperature-sensitive devices), which indicate the scale to which they refer (°C or °F).



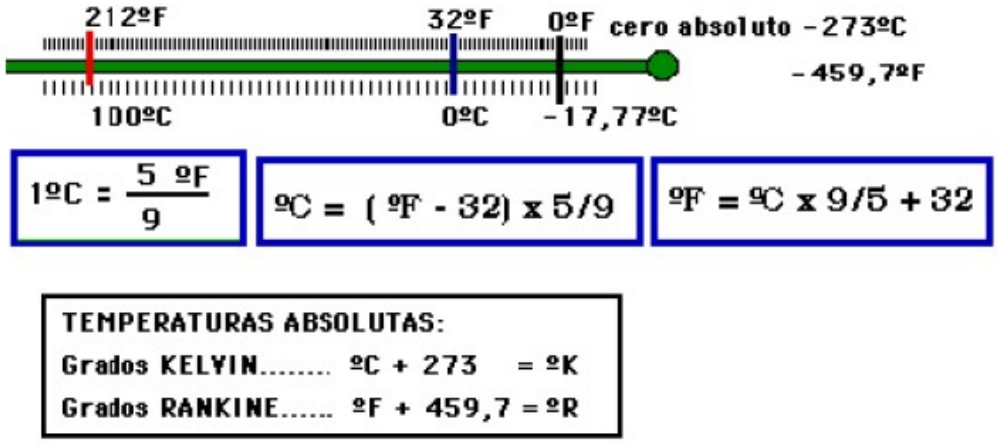
The thermometers in the figure are assumed to be exposed to standard atmospheric pressure (at sea level, whose atmospheric pressure is 1.033 Kg/cm2), for the measurement conditions over water, its vapor or frozen water (ice).

To establish both scales, we use the property of pure water that always thaws at the same temperature (at atmospheric pressure at sea level), establishing this as 0°C or 32°F, and that boils at the same temperature in an open container (at atmospheric pressure at sea level), 100°C or 212°F.

If we divide this scale (the expansion of mercury, alcohol, a metallic element, etc.) into 100 parts, we get 1 degree Celsius (1°C), and if we divide it into 180 parts, we get one part equivalent to 1 degree Fahrenheit (1°F).

We can convert from one scale to the other using the following:

(°C x 9/5 + 32) = °F (°F - 32) x 5/9 = °C



HEAT

Unit of Heat: We will define the unit of heat as the amount of heat required to raise the temperature of one unit of pure water by one degree within a given range (15°C or 17.5°C for the calorie).

According to the units, we have:

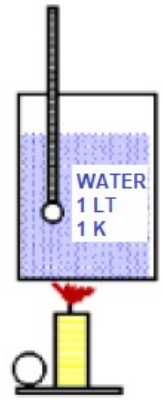
1 Kilocalorie = raising the temperature of 1 kg of pure water by 1°C.

1 BTU = raising the temperature of 1 pound of pure water by 1°F.

We can establish the relationship between the two by relating their base units:

Kilocalorie x 3.968 = BTU x 0.252 = Kilocalorie

As we can see, we are talking about the two most common systems of units in our region: the "metric" system (Kilocalorie) and the "English" or "imperial" system (BTU).



KCAL
1 KILOCALORIE = HEAT REQUIRED TO RAISE THE TEMPERATURE OF 1 KG OF WATER BY 1°C

BRITISH THERMAL UNIT (BTU) = HEAT REQUIRED TO RAISE THE TEMPERATURE OF 1 LB OF WATER BY 1°F

1 BTU = 0.252 KCAL 1 KCAL = 3.968 BTU

SATURATED STEAM IS STEAM THAT HAS THE SAME TEMPERATURE AS THE CONDENSING WATER IN CONTACT WITH IT

SENSIBLE HEAT
100 KCAL ARE NEEDED TO HEAT 1 KG OF WATER FROM 0°C TO 100°C

LATENT HEAT
539.4 KCAL ARE NEEDED TO EVAPORATE 1 KG OF WATER AT 100°C AT ATMOSPHERIC PRESSURE

1 KG OF WATER VAPOR AT ATMOSPHERIC PRESSURE OCCUPY 1.725 m³ (cubic meters)

1 kg of water vapor at 10 kg/cm² (142 psi) pressure occupies 0.18 m³ (cubic meters)

80 kcal are needed to melt 1 kg of ice

THE WATER

Let's talk about water and its physical and chemical properties.

Water (H_2O) is composed of two elements: oxygen (O) and hydrogen (H), specifically two hydrogen atoms (H_2) and one oxygen atom (O).

It is found on Earth in very large quantities, almost always with other elements that are dissolved in it. (It is the quintessential universal solvent, and its physical and chemical behavior changes when it contains dissolved substances.)

If we consider pure water, we know it has the following properties: It freezes at 0°C (32°F) and boils at sea level in an open container at 100°C (212°F). One liter of water (dm^3) at 4°C weighs 1 kg (at sea level). If we boil it in a closed container without air (or other gases), we will see that each temperature corresponds to a specific pressure. (This relationship occurs with saturated steam).

To melt 1 kg of ice, we need 80 kilocalories, and to heat 1 kg of water by 1°C, we need 1 kilocalorie (kilo = 1000, or 1000 "small" calories).

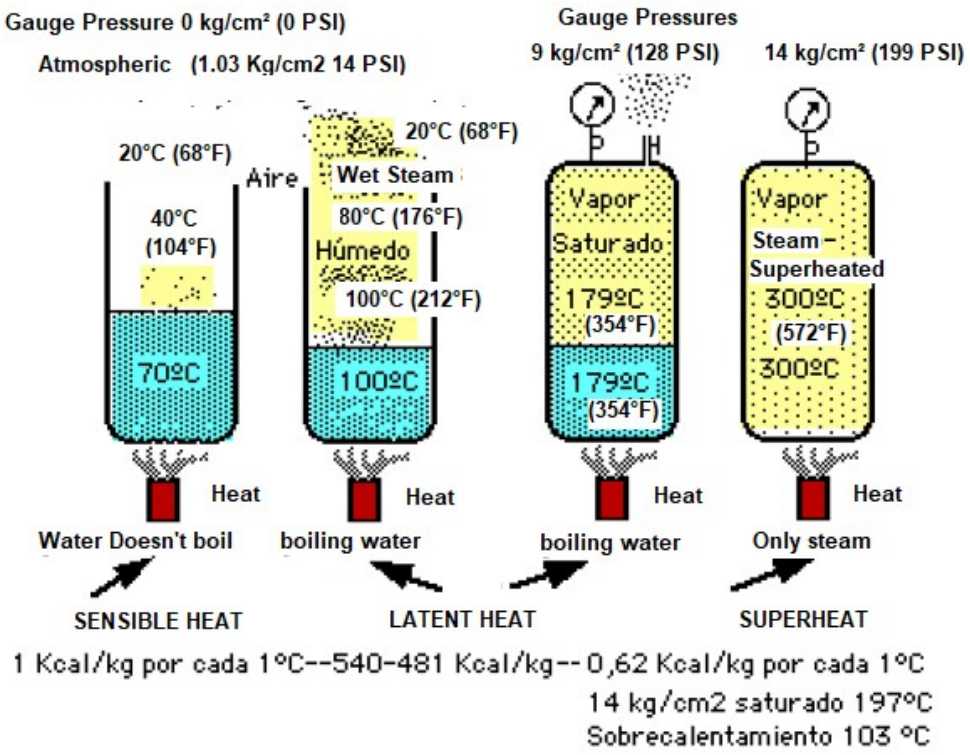
When we take a container with 1 kg of pure water and heat it from 0°C to 100°C (212°F), we will need approximately 100 kilocalories. This heat, which we can "feel" and which increases with temperature, is called sensible heat.

We will see that when we heat pure water in an open container (in the atmosphere and at sea level, see previous sketch), the water boils at 100°C (212°F). If we continue heating, we will see that the temperature remains at 100°C (212°F), but the water evaporates (transforms into steam).

This heat that transforms the water into steam is called latent heat (heat that is in the form of energy—that is, it transformed the liquid into a gas—steam—which, upon cooling, transforms back into the liquid—water—giving us that heat again).

Let's clarify what boiling means: this occurs when a large movement is observed within the water, caused by the rapid release of vapor bubbles. In other words, the pressure of the generated vapor

exceeds the pressure of the surrounding water and vapor. (Evaporation can occur even if the boiling point is not reached).



The atmosphere is composed of water vapor and gases (oxygen, nitrogen, etc.). This water vapor has a partial pressure corresponding to the temperature of this mixture, and the amount of vapor present in the atmosphere—forming ambient humidity (expressed in meteorology as % relative humidity)—comes from the evaporation of oceans, lakes, rivers, etc. There is a maximum (saturation, "dew point") for each temperature and atmospheric pressure.

If we seal the container and heat the water (allowing all the air to escape, pushed out by the steam), we will see that the steam, having no room to expand, begins to increase the pressure inside the container (the pressure inside before sealing is 1 atmosphere absolute, or 1.033 kg/cm² - 14.7 psi - and the gauge pressure is 0).

It can be observed that the temperature of the water and the steam is the same and that both rise in a correlated manner (each temperature corresponds to a specific pressure). If we cool and then reheat the container, these temperature and pressure values will

return to the same levels as before (provided there are no other gases mixed with the water vapor).

This steam that is generated and is in contact with the water is called saturated steam (dry or wet steam). In the case of boilers, because there is water circulation inside, by "carrying" tiny droplets, we can have steam that is not dry saturated, but saturated with moisture. This is called wet steam, and the total amount of steam (which we express as 100%) minus the moisture content, which represents its percentage by weight, is called the "Steam Title" (representing the percentage of dry saturated steam by weight).

If we heat a closed container of water (with a small amount of water), that is, if we manage to completely evaporate the water, the steam, upon receiving heat, will have a higher temperature and pressure. However, the temperature will be higher than the pressure in the previous case; this steam is superheated steam. (This steam is dry and can absorb water until it reaches saturation, lowering its temperature).

The relationship between the water temperature and the pressure of saturated steam in a boiler is found in the Saturated Steam Tables.

SATURATED STEAM TABLE

TABLAS DE VAPOR SATURADO

	pressure	temperature	total heat	water heat	steam heat	volume	
	presión	temperatura	calor total	calor agua	calorvapor	volumen	
PSI	ATA	C°	Kcal/Kgr.	Kcal/Kgr.	Kcal/Kgr.	m3/Kgr.	
0.7	0.05	32.55	611.3	32.55	578.9	28.7300	
2.8	0.20	59.67	623.1	59.61	563.5	7.7930	
7.1	0.50	80.86	631.6	80.81	550.8	3.3010	
14	1.00	99.09	638.5	99.12	539.4	1.7250	Presion atmosfera al nivel del mar 1.033 Kg/cm2 14.7 PSI
28.4	2	119.62	645.8	119.87	525.9	0.9016	
42.7	3	132.88	650.3	133.40	516.9	0.6166	
56.9	4	142.92	653.4	143.60	509.8	0.4706	
71.1	5	151.11	655.8	152.10	503.7	0.3816	
85.3	6	158.08	657.8	159.30	498.5	0.3213	
99.5	7	164.17	659.4	165.60	493.8	0.2778	
114	8	169.61	660.8	171.30	489.5	0.2448	
128	9	174.53	662.0	176.40	485.6	0.2189	
142	10	179.04	663.0	181.20	481.8	0.1981	Presion de trabajo 10 Kg/cm2 147 PSI
156	11	183.20	663.9	185.60	478.3	0.1808	
213	15	197.36	666.6	200.60	466.0	0.1343	
284	20	211.38	668.5	215.8	452.7	0.1016	

(Saturated steam table in imperial units at the end of the chapter)

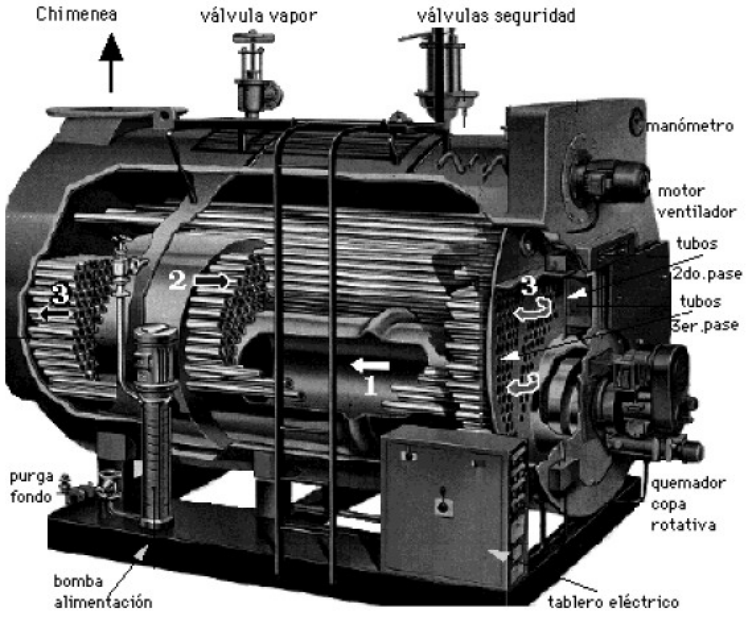
Example: Given that a pressure of 1 ATA = 1 kg/cm² (14.2 PSI) (not to be confused with atmospheric pressure, where 1 atmosphere is equal to 1.033 kg/cm²).

For a pressure of 11 ATA (Technical Atmosphere Absolute), which is approximately equal to 10 kg/cm² gauge pressure, or 156 PSI, the temperature is 183.2 °C for both water and steam.

To heat water to its vaporization temperature (183.3 °C) from 0 °C, 185.6 kilocalories per kg of water are needed, and to vaporize that kg, 478.3 kilocalories are required. In other words, to vaporize 1 kg of water at a pressure of 11 Atmospheres Absolute Technical (10 kg/cm² relative to 0 gauge pressure) starting from 0°C, we need a total of 663.9 kilocalories. These values are in the steam tables. See tables at the end.

This allows us to calculate the amount of heat needed to produce each kg of (dry saturated) steam at a given pressure, simply by knowing the boiler's operating pressure and the feedwater temperature:

Heat required to evaporate 1 kg of water = Total heat of steam - Heat of feedwater. (This heat will be greater due to heat losses in the boiler).



CALDERA HUMO TUBULAR DE 3 PASES

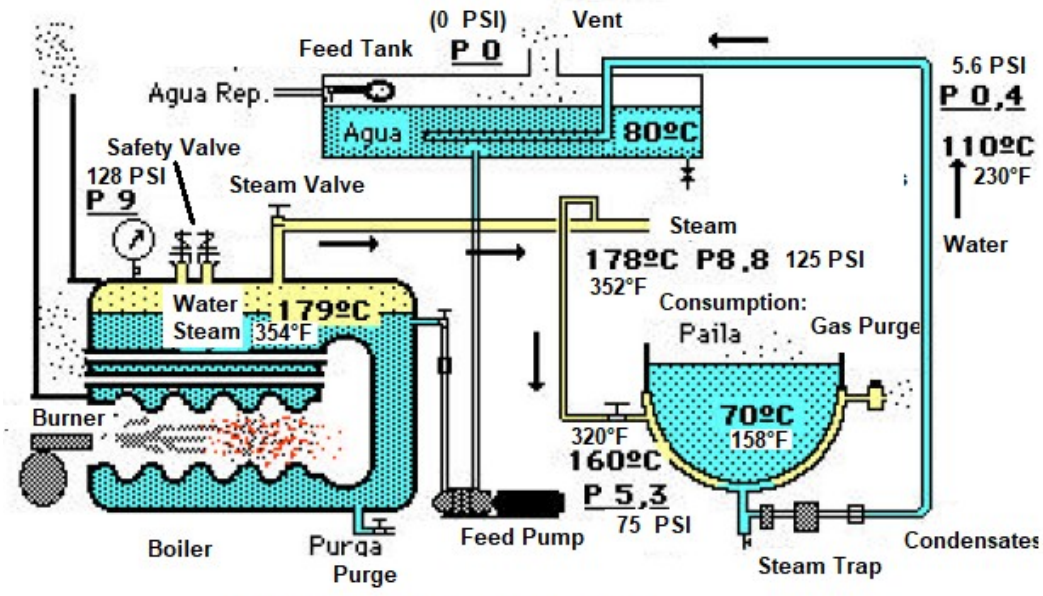
As the example shows, the most significant heat per kg is due to latent heat or heat of vaporization, which is typically used by condensing the steam at the point of use.

Just as knowing the pressure of saturated steam allows us to determine its temperature, knowing only its temperature will also allow us to determine its pressure. (Remember that saturated steam is steam that is in contact with the water that produces it and does not receive any more heat as it evaporates).

From the above, it follows that if we know the pressure of saturated steam, we can determine its temperature and the amount of heat it can provide where we use it:

Heat provided = Total Heat of the steam - Heat of the condensed water.

(The condensate is generally at a temperature above 100°C (212°F) because its pressure is higher than atmospheric pressure (it is called superheated water) - see table - and once at atmospheric pressure, it releases some of its heat, forming flash steam. This re-evaporation occurs to achieve equilibrium between the temperature and pressure corresponding to saturated steam (atmospheric pressure, since the feed or condensate tank is connected to the atmosphere).



water cycle and steam transporting heat

We see that in the cycle that water and steam undergo, their temperatures and pressures will be related as long as they are in direct contact (dry or wet saturated steam).

This relationship will only be altered if we heat the steam alone or produce a decrease in pressure by increasing the volume occupied by the steam without adding heat (as in the case of lowering the pressure with a pressure regulating valve).

We will normally find steam with moisture, but for practical purposes, we can consider it dry saturated steam. (The quality of the steam depends on the chemical and physical conditions in the boiler: the firing rate, sudden openings of fuel, pH, TDS, contaminants, etc.).

Saturated steam in imperial units:

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PROPERTIES OF SATURATED STEAM

Steam Pressure PSIG/ Inches Hg	Saturated Temp °F	Sensible Heat BTU/lb.	Latent Heat BTU/lb.	Total Heat BTU/lb.	Specific Volume (liquid) cu ft/lb	Specific Volume (vapor) cu ft/lb
29.743	32	0	1076	1076	0.01602	3306
20	161	129	1001	1130	0.01640	75.32
10	192	160	982	1143	0.01658	39.21
0	212	180	970	1150	0.01671	26.80
5	227	195	960	1156	0.01682	20.38
10	239	208	952	1160	0.01692	16.49
15	250	218	946	1164	0.01700	13.88
25	267	236	934	1170	0.01714	10.58
50	298	267	912	1179	0.01743	6.69
75	320	290	895	1185	0.01765	4.91
100	338	309	881	1190	0.01785	3.89
125	353	325	869	1193	0.01802	3.23
150	366	338	857	1196	0.01818	2.76
200	388	362	838	1200	0.01847	2.14
250	406	382	821	1202	0.01873	1.74
300	422	399	805	1204	0.01897	1.47

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